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THE TMB AUTOMATIC SHIP'S MOTION RECORDER

by

Norman H. Jasper

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THE TMB AUTOMATIC SHIP'S MOTION RECORDER

by

Norman H. Jasper

ABSTRACT

This report describes the development of an automatic ship's motion recorder which records the ship's rolling, pitching, and heaving accelerations as well as the rolling and pitching angles. The recorder has provision for automatic sampling of data at preselected intervals of time, and it can operate continuously for weeks on shipboard without requiring human attention. The apparatus may also be used to record quantities other than those mentioned, for example, pressures and strains.

The recorder and the transducers are evaluated on the basis of their performance so far, and further worthwhile developments are suggested in the report.

INTRODUCTION

The function of the TMB automatic ship's motion recorder is to record automatically the heaving, rolling, and pitching accelerations as well as the rolling and pitching angles of ships. Its record provides the data needed for a statistical analysis of ships' motions. Briefly, the recorder registers the output of five transducers as a function of time, for a predetermined duration, at preselected intervals of time; that is, it performs a sampling operation. The unit described in this report is set to record for a duration of two minutes at hourly intervals.

This device was developed as part of a program, authorized by the Bureau of Ships,[1] to study the strength of ships at sea.* There are many occasions when it would be of considerable value to know the actual motions which ships may be expected to have at sea, for example in designing masts, flight decks, hulls, and supports for machinery and instruments as well as in the design of equipment mounted aboard ships and—to mention quite a different field—in the study of physiological aspects of ship motions.

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[1]References are listed on page 26.

*A general discussion of a proposed program for the study of the strength and motion of ships at sea will be given in another TMB report. See also References 2 and 3.

To date there is but little organized information available on the actual rolling and pitching angles of ships and even less is known about the bodily acceleration of ships. It is the function of this recorder to provide such information without requiring personnel for the operation of the equipment. The present model of the TMB automatic ship's motion recorder was installed on a Coast Guard weathership during a 2-month tour of duty in the North Atlantic in the spring of 1951. The recorder and pickups operated continuously during this time and gave satisfactory service.

This report will give some background leading to the development of the apparatus; the recorder and the pickup devices will be discussed and recommendation for further development will be made.

BACKGROUND AND GENERAL DESIGN CONSIDERATIONS

The lack of information on the motions of ships at sea is due primarily to the physical and financial difficulties that have been present in attempts to obtain such full-scale data. The cost involved in providing instrumentation and personnel, with use of the ordinary methods of recording data, prohibits such trips except on rare occasions; therefore such methods cannot provide a sufficiently broad basis from which mean and probable peak values can be determined for given ships operating in the various seas.

It was considered, therefore, that much profit might be derived from the development of some automatic device which would record the desired quantities over long periods of time and which could be installed aboard a ship and left there unattended, except for the purpose of removing the data at intervals of several weeks or months. Obviously the apparatus would need to be rugged and, if it is to be utilized on a large scale, inexpensive.

Quantities that enter directly into structural design are the accelerations associated with the rigid-body motions of the ship as well as the angular position of the ship in the gravity field. These accelerations vary relatively slowly with time and their magnitude is generally less than the acceleration of gravity. Throughout a ship there are usually high-frequency local vibrations present, which are undesirable for our purpose since they give rise to accelerations of the same or greater magnitude than those due to the rigid-body motions of the ship. It is necessary that measurements be kept free of these higher-frequency components so as not to obscure the desired information.

The measurement of angular acceleration involves considerable difficulty. There does not appear to be a suitable instrument available which will measure the required rather low values of angular shipboard acceleration with sufficient accuracy. A measurement of angular acceleration may be obtained by

utilizing a set of linear accelerometers. Signals proportional to the rolling and pitching angles may be obtained from gyroscopic stable elements. It is necessary that the stable element have a long natural period as compared with the periods of the motions to be measured.

It was decided that a device should be developed which would measure and record the heaving, rolling, and pitching accelerations of a ship and, in addition, have two spare channels available which could be utilized for recording the rolling and pitching angles or, alternatively, some other quantity such as strain. To reduce the cost, standard components were used as much as possible, and refinements in the prototype model which were not needed for an effective evaluation of the suitability of the basic apparatus were omitted.

Since analysis of records is a laborious and time-consuming operation, the apparatus was designed to be used as a sampling device, that is, to record the data only for a relatively short duration at preselected intervals of time. Thought was also given to providing means which would cause a record to be made only when the value of the measured quantity exceeded a preselected magnitude. However, this was considered to be one of the unessential refinements.

Inasmuch as the equipment was intended to operate aboard ship over long periods of time, including storm periods, it was felt desirable to require that the apparatus operate from power normally available on most ships at the voltage regulation of such power sources. Furthermore, the instruments and the recorder had to operate satisfactorily under the environmental conditions aboard ship at all time.

Appendix 1 will give the specifications that were established in view of the considerations just discussed. The recorder and the accelerometers which are at present used with it, have been developed at the Schaevitz Engineering Company, Camden, New Jersey, in accordance with specifications drawn up by the David Taylor Model Basin.

THE RECORDER

The recorder is essentially a direct-recording oscillograph which has provision for automatic sampling and which is designed to operate continuously for weeks on shipboard without human attention. The unit is shown in Figures 1 through 6. Its over-all size is 19 3/4 inches wide, 15 3/8 inches high, and 15 1/4 inches deep. All necessary amplifiers, servo-motors, etc., are contained in the case. The only external connections to be made are those to the transducers (pickups) and to a 60-cycle 110-volt a-c power source. The recorder has a frequency response which is flat within 5 percent from d-c to 1 cycle per second. Higher frequency signals are attenuated.

Figure 1a - Front

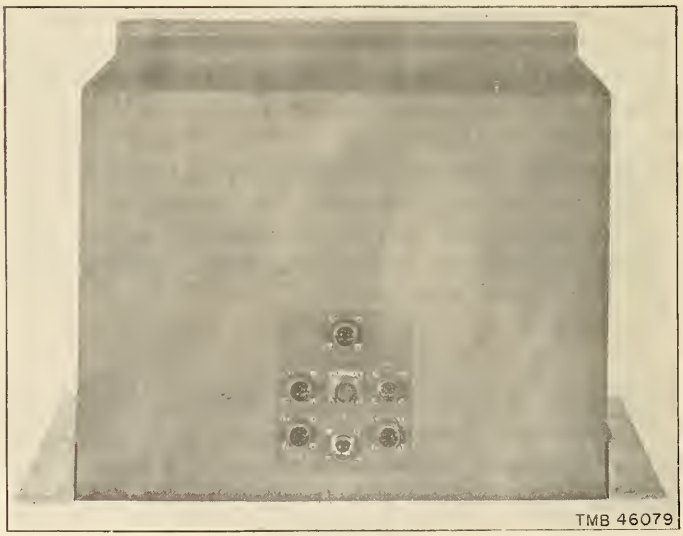


Figure 1b - Back

Figure 1 - TMB Automatic Ship's Motion Recorder

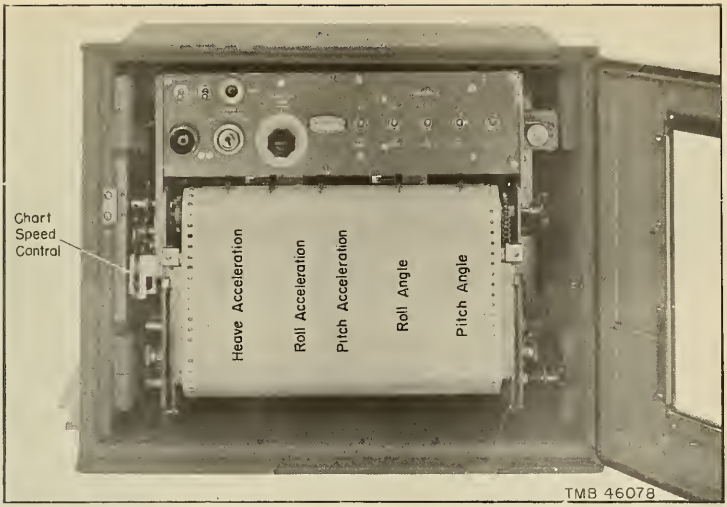


Figure 2 - Recorder with Front of Case Opened

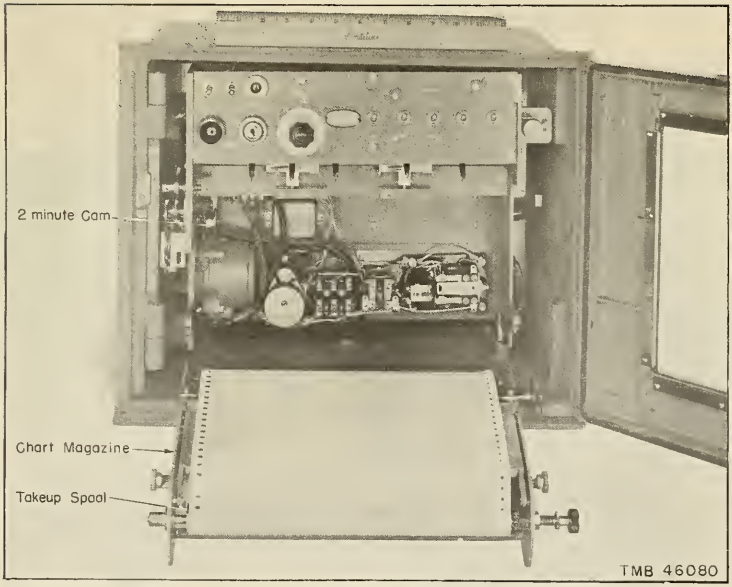


Figure 3 - Recorder with Chart Magazine Removed

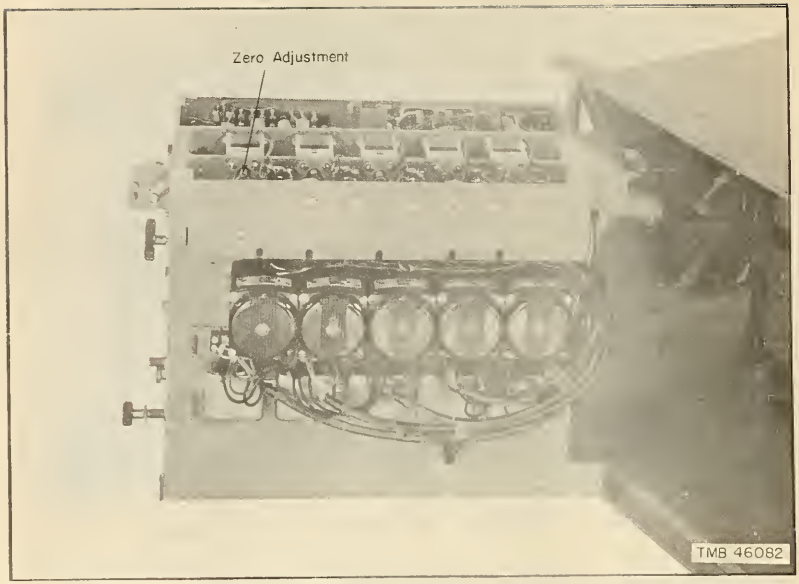


Figure 4 - Back of Control Panel

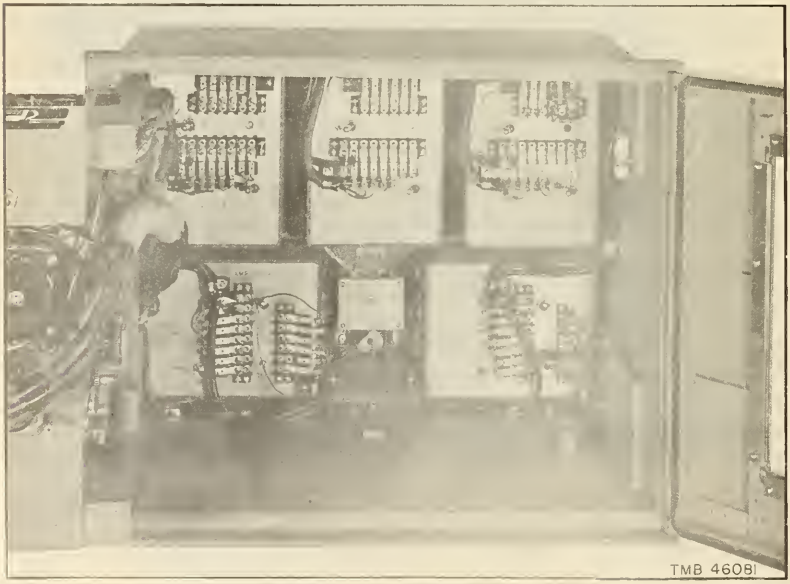


Figure 5 - Amplifiers Installed in Recorder

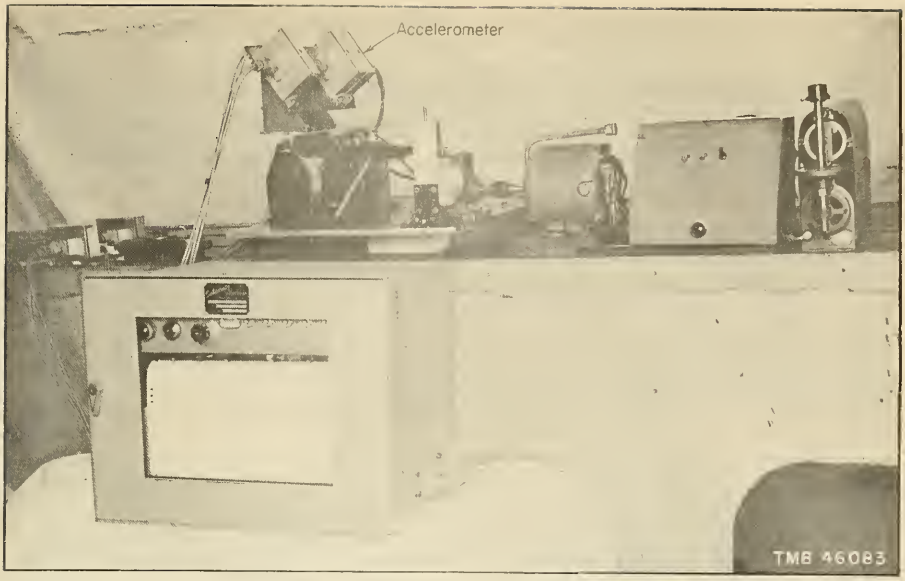


Figure 6 - Recorder and Accelerometers

Figures 2 and 3 show a front view of the recorder with its airtight cover opened. There are 5 channels and 2 sensitivities (X1 and X3) available per channel. The lower sensitivity will usually be used. Each recording pen has a chart strip 2 inches wide provided for it, and positive stops are present which limit the travel of the pens to this value; the pen drive motors cannot be overloaded. The chart speed-control lever can be seen at the far left of the photographs. It permits a selection of speeds of 1/2 or 1 inch per minute; these chart speeds are sufficient to give ample resolution of the oscillograms for the purpose intended. The recording chart (Figure 7) has a plastic-coated surface which is sensitive to pressure applied by the recording pens; the surface does not smudge with ordinary handling.

Normally the unit will be used as a sampling device, and a record of 2 minutes duration will be made at hourly intervals. The procedure is as follows: The power is turned on and about one hour is allowed for the unit to warm up. Then the chart drive switches are thrown to the "ON" and "TIMED" positions. The recorder will now take a record at hourly intervals. If it is desired to record continuously, it is merely necessary to throw the chart drive switch to the "CONTINUOUS" position. If, while the recorder is set for the automatic cycling operation, it is desired to record continuously for a

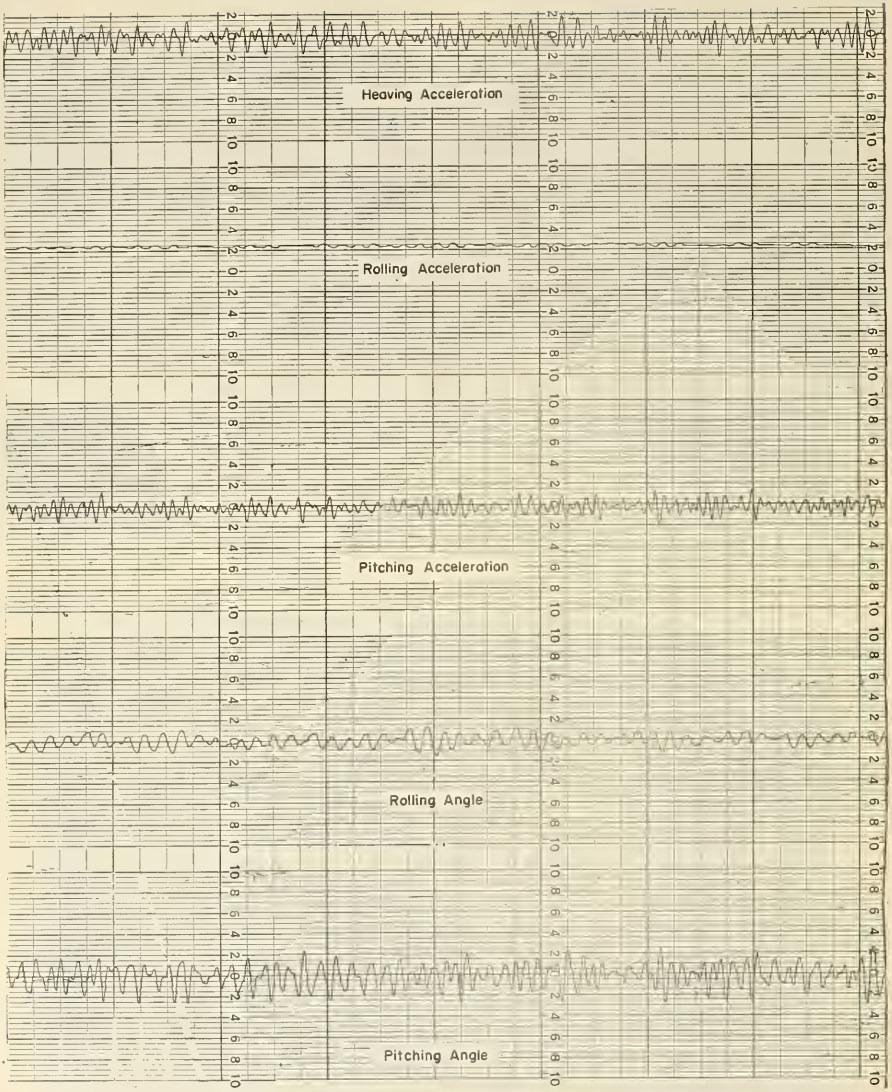


Figure 7 - Sample of Recording Chart

predetermined period of from 5 minutes to 113 minutes, it is merely necessary to turn the "MANUAL SET TIMER" to the desired time interval; the recorder will immediately start to record and at the end of this interval will automatically return to the automatic cyclic operation.

The supply and takeup spools for the chart paper are mounted in a single removable magazine as shown at the bottom of Figure 3. One spool is sufficient for 50 days automatic operation at the lower chart speed. Different chart speeds could readily be obtained by a change of gear ratios. The entire unit may be mounted in a standard rack, or it may be shock-mounted.

The over-all sensitivities of the several channels are given in Table 1.

TABLE 1

Sensitivity of the Several Channels of
TMB Automatic Ship's Motion Recorder

Channel	Quantity Measured	Range on Attenuator X1 (full scale)	Range on Attenuator X3 (full scale)	Sensitivity millivolts per inch deflection	Over-all Sensitivity of Transducer and Recorder (Attenuator X1)
1	Heave Acceleration	± 1 g	$\pm 1/3$ g		1 inch/g*
2	Roll Acceleration	± 1 rad/sec^2	$\pm \frac{1}{3}$ rad/sec^2	9	2 inches/g* or 1 inch/rad/sec^2**
3	Pitch Acceleration	$\pm \frac{1}{2}$ rad/sec^2	$\pm \frac{1}{6}$ rad/sec^2	18	4 inches/g* or 2 in/rad/sec^2**
4	Roll Angle	45°	15°	9	
5	Pitch Angle	15°	5°	18	

*g is the acceleration of gravity.

**Sensitivity of 2 linear pickups 16.1 feet apart, wired in series opposition.

THE TRANSDUCERS

The recorder may be used to record the voltage output of a variety of transducers provided the frequency of this voltage is the same as that required to drive the two-phase pen motors. For our purpose, however, we will discuss the operation of the particular transducers that have been used to determine the heaving, rolling, and pitching accelerations as well as the rolling and pitching angles of the ship.

The accelerations are measured by pickup devices which are essentially identical. These accelerometers utilize a "linear variable differential transformer" (LVDT) as the sensing element.

This transformer consists of a secondary and two primary windings wound on the same axis, with the secondary located between the primaries. The primaries are connected in series so that the voltages they induce oppose each other. When an iron core is placed on the axis of the LVDT and symmetrically located with respect to the primaries, the output of the secondary is a minimum (practically zero). This is the null position. When the core is moved in one direction from the null position, the voltage induced in the secondary by one primary will increase while that induced by the other primary will decrease. The net result will be an increase in output voltage directly proportional to the core displacement, and the phase of this voltage will depend on the direction of the displacement from the null position. To operate as an accelerometer the displacement of the core is made proportional to acceleration. A signal proportional to angular acceleration is provided by connecting the output of two linear accelerometers in series opposition. On the Coast Guard weathership, two linear pickups were spaced 16.1 feet apart to give the desired angular acceleration signal.

A signal proportional to the rolling and pitching angles may be obtained either directly from the output of a stable element, or, alternatively from a potentiometer driven by a servo system which in turn is actuated by a stable element. For greater accuracy more refined methods can be devised.

It should be noted that the transducers as well as the recorder and amplifiers are designed for 60-cycle 110-v a-c operation. They could just as well have been designed for an a-c supply of higher frequency.

The accelerometers were obtained from the Schaevitz Engineering Co.; their specifications are given in Table 2.

PRINCIPLE OF OPERATION

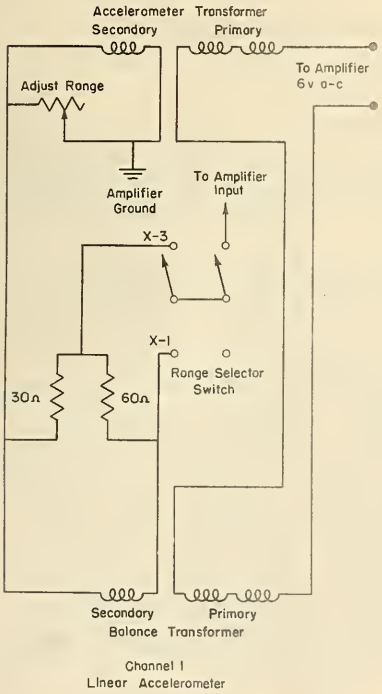
In the schematic diagram of Figure 8, it is seen that the outputs of the secondaries of two differential transformers (LVDT) are connected in series opposition. One LVDT is located in the recorder, see Figure 4. Each produces a 60-cycle a-c output.

The sum of the outputs of the two LVDT's is amplified, its phase is shifted electrically 90 degrees, and then impressed on one phase of a two-phase motor; the other phase of the motor is directly excited from the a-c power supply. This two-phase motor in turn drives both the pen and the core of the balance LVDT until the output of the balance transformer's secondary is equal to that of the accelerometer's secondary, resulting in zero voltage

TABLE 2

Specifications for Schaevitz Accelerometers

Accelerometer	Designation by Manufacturer	Primary		Secondary		Sensitivity - Open Circuit mv. output per volt input at 60-cycle a-c for 0.001 inch core displacement
		Resistance per Coil ohms	Number of Turns per Coil No. 36 HF Wire	Resistance per Coil ohms	Number of Turns per Coil No. 40 HS Wire	
Heave	DA-1	15	250	400	2500	1
Roll	DA-2	15	250	400	2500	1
Pitch	DA-2	15	250	400	2500	1



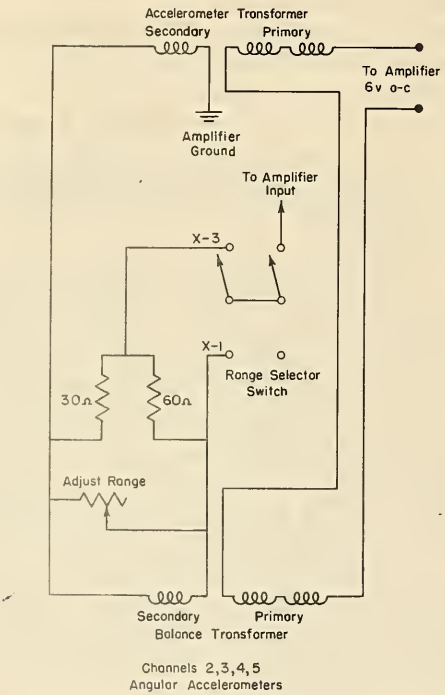


Figure 8 - Schematic Diagrams of Null Balance Circuits

input to the amplifier. In short, the follow-up system is arranged so as to balance the sum of the transformer voltages to zero.

If greater pen deflections are desired for a given transducer signal, it is only necessary to tap off a smaller portion of the output of the balance transformer's secondary since this will require the motor to drive the core of the balance LVDT through a greater distance in order to null the system; and of course, the pen motion is directly proportional to the core motion.

The primaries of both transformers are connected in series, likewise the secondaries. This insures freedom from disturbances due to changes in line voltage; since line voltage changes will affect each transformer equally, the net change will be zero.

Figure 4 shows the location of the balance LVDT's and the adjusting screws for manually moving their cores in order to center the corresponding pen on the chart. The screws marked "ADJ RANGE" permit adjusting the sensitivity of the several channels. The amplifiers, one for each channel, may be seen in Figure 5.

Detailed circuit diagrams and operation instructions are given in Appendix 2.

DISCUSSION AND EVALUATION

In discussing the instrumentation it will be appropriate to discuss the recorder and the transducers separately since they are, in fact, complete in themselves.

The recorder and transducers were installed on the Coast Guard weathership USCGC CASCO, a vessel 310 feet in length, while on a duty tour in the North Atlantic from 11 March to 12 April 1951, a total of 32 days. The equipment was operating during this entire trip except for a day's interruption due to failure of a relay, which has since been replaced by a more rugged unit. The performance of all units was entirely satisfactory during this trip—especially when one considers that it was the first time the equipment had been given a service test. The maximum measured values during this voyage were: Roll of 37.5 degrees double amplitude, pitch 18 degrees double amplitude, heaving acceleration 0.8 x gravity, pitching acceleration 0.5 radians/sec^2, and rolling acceleration 0.20 radians/sec^2. All of these are double amplitude or peak-to-peak values. The voyage may be considered to have provided rolling, heaving, and pitching conditions of the maximum order of magnitude to be expected.

The recorder in its present form did the job well for which it was designed. It has shown itself to be rugged and reliable with the exception of two minor items, namely the relay failure mentioned above and a cam follower which should be made of somewhat heavier steel strip. It would be a great convenience to incorporate into the recorder mechanism a device which would automatically stamp the date and time on the record whenever a record is made. Other desirable refinements would be a provision for a greater chart capacity, say 200 feet, and two or three additional recording channels in order to permit recording of strain, ship's speed, and heading simultaneously with the other quantities.

The mechanical design of the recorder is very compact and utilizes subassembly construction, making for easy servicing. Many parts are standard items, readily available. The cost of the recorder including the three accelerometer units was comparatively reasonable, but if additional channels were added the cost may increase somewhat disproportionally because a standard chassis might not be available.

Analysis of the records obtained from the CASCO sea trials has been made in terms of the number of cyclic variations of the magnitudes (roll, pitch, etc.) that fell within given limits. Such an analysis can be presented rather conveniently in the form of frequency distribution curves. This analysis, although readily made by inexperienced personnel, is tedious; it could be performed automatically by means of a counter system similar to the type that has been under development for the strain cycle gage, see Reference 3. Both the chart recording and the statistical analysis provided by the cycle-counter data could be made available at the same time. The development of this combination of instruments is highly desirable for the study of the strength of ships at sea that is presently underway at the Taylor Model Basin.

The following comments concerning the transducers are in order. The individual accelerometers measure accelerations perpendicular to their bases, and if the ship rolls, the heaving acceleration measured is the component in the centerline plane of the ship. The heave accelerometer will also be affected by the change in the component of gravity along its sensitive axis. The error due to the latter cause is generally not serious except for the larger angles of roll; for the largest measured rolling angle this effect would be about 20 percent of the total signal. However, the heave at this time was small. The proper correction can easily be made. Furthermore, these effects are minimized by the fact that, when the heaving is large, the roll is generally small, and vice versa. In measuring the angular accelerations, the effects due to the change in the gravity field or due to linear accelerations are canceled out.

A considerable improvement in the compactness of the installation would be obtained if single angular accelerometers were available; development along this line appears worthwhile. However, the combination of two linear accelerometers, as now used, does give satisfactory service although lacking in compactness. If it is necessary to measure heaving acceleration in the vertical plane, the accelerometer must be mounted on a stable platform; the required corrections can, however, be made from a knowledge of the angle of roll. It is felt on the basis of data obtained so far that the errors actually introduced are small, of the order of 10 percent, and that refinements to correct for the effect of roll on heaving acceleration are not worthwhile.

With regard to the measurement of rolling and pitching angles, it would be desirable to have a small stable element available especially for this purpose with an accuracy of about 1/4 degree in pitch and 1 degree in roll. It should also be mentioned here that a diaphragm pressure gage has been developed at the Taylor Model Basin which will work with this recorder.

The accelerometer and recorder combination is linear within 5 percent from d-c to 1 cps. Lack of calibrating equipment for these low frequencies has limited the extent of calibrations.

One item which may require some additional consideration is the power from which the equipment operates. At present, 110-volt 60-cycle alternating current is used. If, in the future, ship's power of 400-cycle a-c becomes standard, it may be advisable to build the motion recorder and its transducers to operate on the higher-frequency power, which can be done without much difficulty.

To recapitulate the main points covered here: The recorder and transducers, in their present form, are dependable and sufficiently accurate for the intended service. Proposed additional developments are:

a. A time and date stamp.

b. An angular accelerometer (single unit).

c. A small stable element.

d. A counter to count automatically the number of cyclic variations that have occurred.

CONCLUSIONS

1. The recorder performs well in the frequency range associated with the rigid-body motions of ships; it provides sufficient attenuation for high-frequency signals.

2. Both the recorder and the accelerometers may be expected to furnish trouble-free performance over a period of weeks while installed aboard ship. It is not expected that any appreciable servicing will be required between trips.

3. The equipment is relatively insensitive to variation in the supply voltage.

4. The records provide a clear, immediately visible trace and will not be smudged by ordinary handling.

5. The over-all accuracy of the system is sufficient for the intended applications. It is believed to be accurate within 6 percent over the frequency range from d-c to 1 cycle per second. The recorder itself is accurate within 5 percent over the same frequency range.

6. The combination of two linear accelerometers to furnish an angular acceleration signal is somewhat inconvenient to install.

7. The recorder is a versatile unit which may be used as an ordinary recording oscillograph or as a sampling device. It will provide the desired information at a very low cost both in securing and analyzing the data. The records obtained are readily analyzed in terms of the number of times that given magnitudes have occurred. The phase relationship between the several quantities can also be determined with an accuracy depending on the chart speed used.

8. The time required to make certain types of analyses can be reduced to a minimum by adding a counter device to the recorder which will indicate the number of times that given variations have occurred.

9. The recorder in its present form has been used to record linear and angular accelerations as well as angular displacements. In addition, it may be used to record any quantity that is impressed on it provided a properly matched input signal is furnished.

RECOMMENDATIONS

1. An automatic date-stamping device should be incorporated in the recorder.

2. An angular accelerometer should be developed.

3. Small stable elements should be made available for these recorders.

4. Consideration should be given to the addition of channels to the present 5-channel recorder.

5. It is suggested that a number of recorders be built and installed on many ships in order to provide statistical information on the motions, and possibly on the strains and pressures, encountered under various operating conditions. This type of information would be valuable in diverse applications.

6. It is recommended that a project be set up to develop and build a statistical counter device, similar to that described in Reference 3, which would tabulate the variations of rolling and pitching angle, etc., according to the number of cycles of given magnitudes that have occurred. This device would be utilized as an attachment to the TMB automatic ship's motion recorder.

ACKNOWLEDGMENT

Most of the success of the development work is due to the persistent efforts of the Schaevitz Engineering Co. Much of the laboratory and field work carried out in connection with the evaluation of this equipment was done by Mr Q.R. Robinson of the TMB Vibrations Division. The project was accomplished under the direction of the author.

APPENDIX 1

SPECIFICATIONS FOR AUTOMATIC SHIP'S MOTION RECORDER

1. GENERAL DESCRIPTION OF THE INSTRUMENT

The ship's motion recorder is to record simultaneously, on one chart, the output of three accelerometers as well as the voltage output of 2 other transducers whose output may be proportional to angle of roll, pitch, pressure, strain, etc. All channels shall essentially be alike, but provision shall be made to obtain different over-all sensitivities.

The operation of the equipment shall be automatic, not requiring servicing for a period of several weeks. The recorder shall be operated automatically for 2 minutes every hour or other selected time duration at desired intervals. Transducers are to be energized continuously. A dial-type indicator, graduated from 0 to 2 hours, is to be incorporated in the recorder so that, at will, continuous recording within this range can be accomplished by setting a knob on the timer. Another switch, wired in parallel, is to provide manual "on-off" control of the chart drive. The recorder should incorporate suitable attenuators on all channels.

2. ACCELEROMETERS

a. Amplitude Range

1 Linear Accelerometer	± 1 g
1 Angular Accelerometer	± 1 radian/sec^2
1 Angular Accelerometer	$\pm 1/2$ radian/sec^2

b. Frequency Range — 0 to 3 cps

c. Damping — About 0.7 of critical damping

d. Linearity

± 30 percent of actual value at minimum discernible deflection*

± 5 percent of actual value at 1/10 full scale

± 1 percent of actual value at full scale

e. Temperature range over which equipment will be used is 30° to 110° F.

f. The temperature stability of the accelerometers is to be such that, if a stream of water at a temperature from 32° to 100° F. is passed over the gage for a period of 10 minutes, there shall be no change in output of the gage in excess of 2 percent of full-scale output.

*Minimum single amplitude of deflection discernible on the recording chart is 0.005 inch.

3. ROLL AND PITCH ANGLE TRANSDUCERS

a. Amplitude Range

Roll	± 45 degrees
Pitch	± 15 degrees

b. Frequency Range 0 to 3 cps

c. Linearity

Roll	± 1 degree
Pitch	± 1/4 degree

4. AMPLIFIER AND RECORDER

a. There will be a total of 5 channels.

b. The frequency response of the accelerometer channels should be such as to give at least 95-percent attenuation at 5 cps and less than 10-percent attenuation at 1 cps. The frequency response of strain-gage channels shall be such as to give less than 5-percent attenuation at 5 cps.

c. Paper speed of recorder is to be 1/2 inch and 1 inch per minute. A record is to be obtained by scribing on pressure-sensitized paper or the equivalent thereof. Provision is to be made for a chart rewind mechanism.

d. Power supply to the recorder will be 110-v a-c 60-cycle at normal regulation (± 10 percent).

e. Accelerometer channels - Sensitivity

The amplifiers are to have the same sensitivity as for all other channels, but attenuators shall be provided to give over-all sensitivities of:

1 inch and 3 inches per g for linear accelerometer

1 inch and 3 inches per radian/sec^2 for angular accelerometers

The tolerances for the over-all sensitivities shall be the same as specified for the linearity of the accelerometers (Item 2d).

5. ADDITIONAL REQUIREMENTS

a. The equipment should be rugged and not require attention for several weeks.

b. The equipment is to withstand salty, humid atmospheres.

c. An "on-off" switch is to be provided to energize or de-energize the complete unit. A locking device should be provided to prevent tampering with this switch.

d. The chart drive should have the following controls (listed here in the order in which they take precedence):

i. Manual "on-off" switch

ii. Manually set timer for continuous operation up to an interval of 2 hours. (This would bypass Switch i.)

iii. Automatic control which will actuate the chart drive for a predetermined period of time every hour, or other preselected interval, unless bypassed by the preceding switches.

6. The contractor is to furnish plans and an instruction book with the equipment.

APPENDIX 2

INSTRUCTIONS

A. RECORDER SYSTEM

1. CAUTION

AC-DC amplifiers are used in this system. Therefore, when the amplifier is mounted, one side of the power line is automatically connected to the case. It is necessary to be absolutely sure that the case is at ground potential before making the external ground connection.

2. Power Supply

Power input connection is at rear of case; use 110-volt 60-cycle alternating current.

3. Circuit Diagrams

See Figures 8 through 10.

4. Operation

Install the recorder and connect it properly to the power source and to the transducers (Note the CAUTION, paragraph 1 preceding). Turn the instrument power on, switch all amplifiers on, and permit the units to warm up for about 15 minutes. The chart drive motor should be in the off position.

To adjust the zero position of the pens proceed as follows. Operate the amplifier "CAL-OFF" switch to the "CAL" position; this shorts out the secondary of the transducer LVDT and changes the circuit from a null-balance to a null-seeking system. Adjust the zeros of the several pens by means of the zero adjustment screws, see Figure 4. Throw the amplifier switch to "Off." Now adjust the sensitivities to the required values by means of the "Range Adjustment" screw. The amplifier gain control may be utilized to reduce hunting; the gain setting does not affect the over-all sensitivity of the recorder.

To record automatically (cycling operation), the "CONTIN-TIMED" switch must be in the "TIMED" position and the "CHART DRIVE, ON-OFF" switch in the "ON" position. If it is desired to record for a definite interval of time between 5 and 113 minutes, switches are left in the same positions as before, and the "MANUAL SET TIMER" is rotated clockwise to the desired number of minutes; at the end of this recording interval the recorder will automatically go back to the cycling operation. If continuous recording is required, the "CONTIN-TIMED" switch is thrown to the "CONTIN" portion.

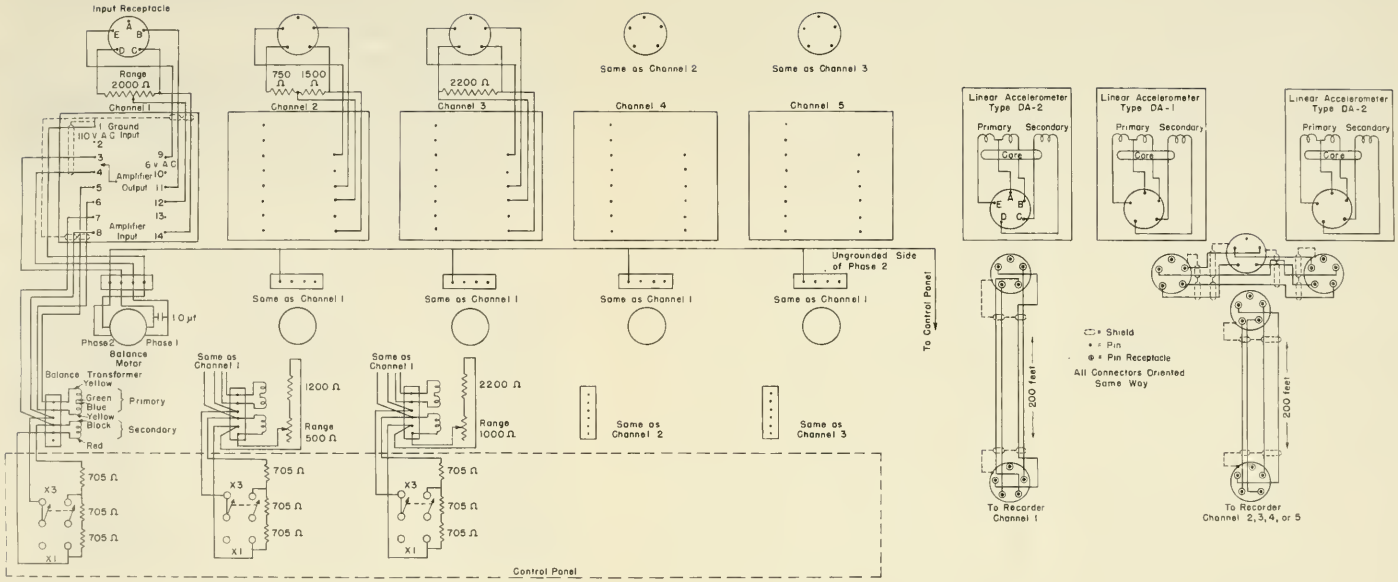


Figure 9 - Schematic Diagram of Amplifier and Accelerometer Circuits

5. Chart Speeds

Chart speed is changed from 1 inch per minute to 1/2 inch per minute by means of a locking lever arm located at the lower left front end of the recorder frame. The "down" position corresponds to a 1 inch per minute speed and the "up" position corresponds to a 1/2 inch per minute speed.

6. Sensitivity Adjustment

The maximum travel of the recorder transformer cores is ± 0.010 inch. This corresponds to full-scale deflection of the pen. For full-scale deflection, it is necessary therefore to make the output of the recorder transformer equal to that of the transducer transformer at the desired full-scale transducer output. This can be accomplished by limiting the output of either the transducer transformer or the balance transformer by placing a shunt resistance across the secondaries or by tapping off a portion of the voltage with a resistance divider network.

7. List of Controls

The various controls are listed below for convenience.

Name	Labeled	Located
Instrument power	"Inst. Power On-Off"	Control panel, front
Chart drive	"Chart Drive On-Off"	Control panel, front
Timing selector	"Chart Drive Contin-Timed"	Control panel, front
2-hr timer	"Manual Set Timer"	Control panel, front
Start 2-hr cycle	"Automatic 2 Hr. Cycle-Push"	Control panel, front
Range selectors	"Sensitivity X3-X1"	Control panel, front
1-hr timer	"One Hr. Timer"	Control panel, rear
Channel 1 range adjustment	"Chan 1 Adj. Range"	Rear of case
Channel 2, 3, 4, 5 range adjustment	"Chan 2, 3, 4, 5 Adj. Range"	Panel (top rear of recorder frame)
Zero adjustment	None	Control panel, rear
Amplifier power	"Power On-Off"	Amplifier panel
Amplifier gain	"Gain"	Amplifier panel
Calibration	"Cal-Off"	Amplifier panel

B. SCHAEVITZ BALANCE AMPLIFIER TYPE 60 AD

1. Description

The balance amplifier is a specialized amplifier designed for use with linear variable differential transformers and two-winding, two-phase

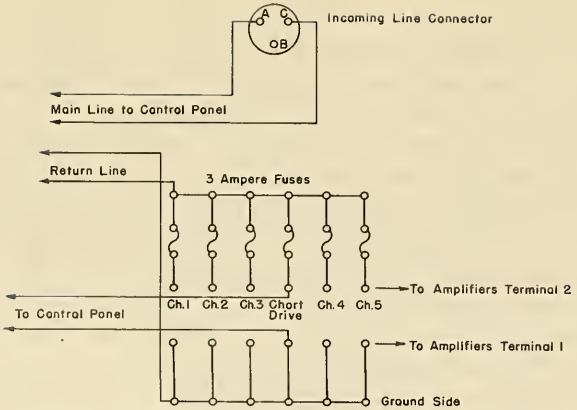


Figure 10 - Schematic Diagram of 110-Volt a-c Power Distribution

induction motors. The voltage amplifier portion consists of 4 resistance-coupled stages, using twin triode 12AX7's. Cathode degeneration is used to achieve stability. The power amplifier, a pentode 6AQ5, is resistively coupled to the voltage amplifier section. No load is provided within the amplifier for the power tube. The plate circuit is completed through the load, which consists of one phase of a 2-phase induction motor, shunted by a 1-μf capacitor.

Primary power for LVDT's is supplied by the amplifier. The phase shift through the amplifier is adjusted so that the output of an LVDT is amplified and applied across the load, 90 degrees in phase from the power-line phase. Since the second phase of the motor is connected across the power line, conditions for maximum torque are thereby established. Sensitivity is rated in terms of the minimum change in input to amplifier which will cause reversal in direction of motor with full torque. In terms of LVDT output this is equivalent to the minimum change in core position about null which will cause the same change in motor operation.

The rectifier power supply is transformerless. It is a grounded negative-voltage doubler using selenium rectifiers. A low hum level is obtained by attention to details such as grounding, isolation filters, and arrangement of components. With this type of supply, one side of the power line is connected to the amplifier ground. This is Terminal 1 on the front panel. It is necessary that this polarity be observed in connecting a power line to the amplifier.

2. Installation and Operation

Three operating controls are provided. The power switch disconnects the amplifier proper from Terminals 1 and 2. The calibrate switch is used when two LVDT's are connected in a null-balance system. It shorts out the secondary of the actuating LVDT and changes the circuit from a null-balance system to a null-seeking system. The gain control, available through an access hole in the front panel, is used to limit the sensitivity to prevent hunting.

No adjustments are required to place the Type 60AD-1 in operation other than to make connections as shown in Figure 11. However, in the 60AD-2 the internal hum balance control must be adjusted. This is done as follows: With the normal output load connected across Terminals 3 and 4, connect a 250-v a-c meter across these terminals. Connect a jumper from Terminal 13 to 14. Adjust the control until a minimum voltage is observed on the meter.

3. Maintenance

Since subassembly construction is used, replacement of parts in maintenance is simplified. The amplifier chassis or the condenser support bracket may be removed from the amplifier panel by unsoldering a few easily located connections. The component board in the amplifier chassis can be freed from the chassis by loosening four screws. Slack in the leads will permit partial withdrawal of this board to allow access to the components.

The first voltage amplifier stage is somewhat sensitive to heater induced hum. It would be difficult to select a replacement 12AX7 for this location unless an oscilloscope were available. A supply of replacement 12AX7's is maintained by the manufacturer. In ordering a 12AX7 it is necessary to state the type of amplifier and whether used for Stages 1 and 2 or 3 and 4.

An oscilloscope is used to select the first stage tube by connecting the scope across Terminals 3 and 4 and connecting a jumper from Terminal 13 to 14. The wave shape observed must be free from sharp points (caused by overloading due to hum input). The a-c voltage measured at Terminals 13 and 14 should be less than 50 volts. The hum control in Type 60AD-2 must be rotated to minimize the output.

4. Specifications

Line voltage - 117-v 60 cycles

Power consumption - 40 va (not including line powered phase of motor)

Sensitivity - 60AD-1 - Complete reversal for 0.00015-inch core motion of Type 100S Schaevitz LVDT

60AD-2 - Complete reversal for less than 0.0001-inch core motion of Type 100S Schaevitz LVDT

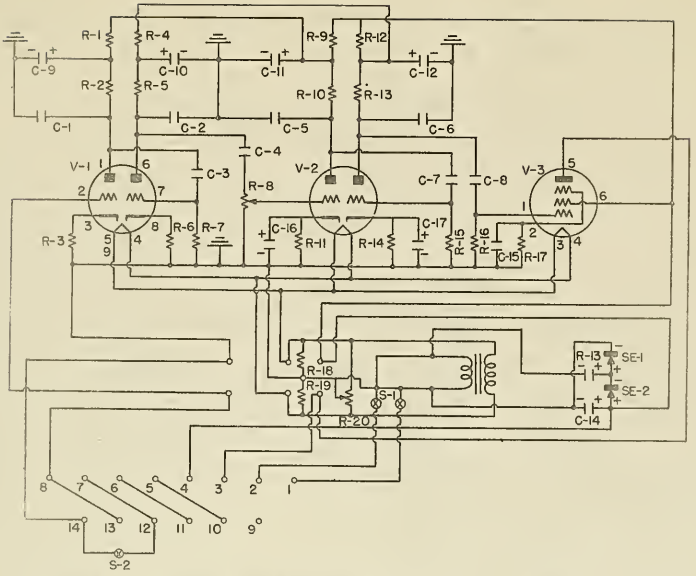


Figure 11a - Schaevitz Balance Amplifier, Type 60 AD-1, Type 60 AD-2

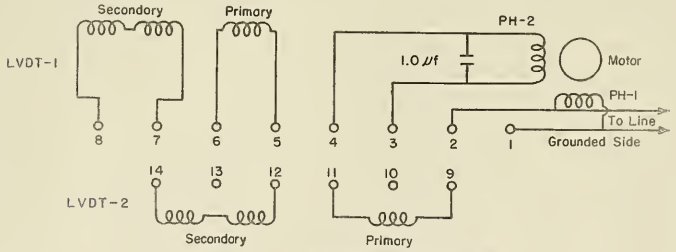


Figure 11b - Null Balance System

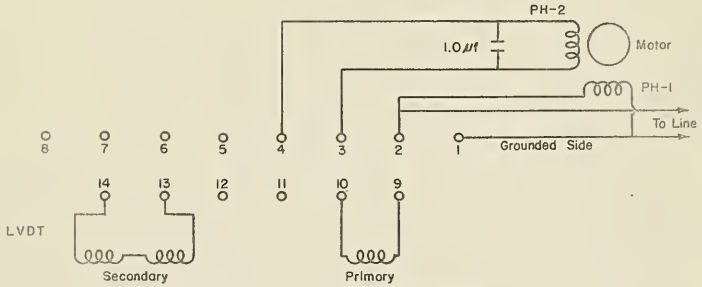


Figure 11c - Self-Positioning System

Figure 11 - Schaevitz Balance Amplifier and Interconnection Diagrams

Power output - Full power 2-phase induction motors to 25 watts
Tube complement - 2 - 12AX7
1 - 6AQ5
Size - 6 5/8 inches by 5 3/16 inches by 4 inches
Mounting centers - 5 inches by 3 5/8 inches
Weight - 4 1/2 pounds

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1. BuShips ltr S29-8(442-440-330) to TMB dated 21 June 1948.

2. N.H. Jasper, "A Statistical Approach to the Longitudinal Strength Design of Ships," Jour. of the Am. Soc. of Naval Engrs., August 1950.

3. N.H. Jasper, "A Statistical Approach to the Measurement and Analysis of Experimental Data on Structures," Jour. of the Am. Soc. of Naval Engrs., August 1951.